The Rift Valleys of Eastern Sinai.

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THE RIFT VALLEYS & GEOLOGY OF EASTERN SINAI.

BY

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READ BEFORE THE INTERNATIONAL GEOLOGICAL CONGRESS, PARIS, AUGUST, 1900.

LONDON:
DULAU & CO., 37 SOHO SQUARE, W.
1901.

LONDON: PRINTED BY STRANGEWAYS AND SONS,
TOWER STREET, CAMBRIDGE CIRCUS, W.C.

INTRODUCTION.

OWING to the kind permission granted me by the Egyptian Government through Sir W. Garstin, Under-Secretary of State for Public Works, and Captain H. G. Lyons, R.E., Director of the Survey Department, I am enabled to lay before you a brief statement of certain results obtained in the course of the Survey of Eastern Sinai during the season of 1898–99. The following remarks are based upon the admirable map prepared by Mr. H. G. Skill, F.R.G.S., who spared no pains to obtain as exact a picture of the country as was possible in the time at disposal. Unfortunately, this map has still to await publication, as there are many others of earlier date to be compiled and printed.

Eastern Sinai has been remarkably neglected by the many scientific writers and travellers who have visited the holy mountain, most of them contenting themselves with an examination of the western side of the peninsula, or with a rapid traverse through the region from Sinai to Akaba, this being especially the case with the south-eastern corner between Dahab and Sherm, an area of which much will be said in the present paper. The only travellers of note in this district, before 1842, appear to have been Rüppell and Burkhardt, and in 1847 Russegger published a map of Syria and Arabia Petrea, which has, at least, the merit of suggesting the mountainous character of the country, and shows one long valley running parallel to the

general outline of the Gulf of Akaba, from near Noweiba to Nebk.

In 1868 the Rev. F. W. Holland, M.A., one of the members of the Ordnance Survey, which made an excellent survey of the western side of the peninsula, under the direction of Sir C. Wilson and Captain Palmer, published a small map in the Proceedings of the Royal Geographical Society, which appears to have remained the standard since that date, and to have been adopted for the interior of the country in the Admiralty Chart of the Red Sea, the result being a curious topographical contrast between the east and west sides — the latter taken from the Ordnance Survey—which it is hoped will disappear when our own contribution is printed. Professor Hull's fault region touches our district to the north, he having crossed by the usual Akaba route.

Topography of Eastern Sinai.

The traveller who enters Sinai by the quarantine port of Tor, will, when standing on the shore and looking eastward, see a prominent mountain range running roughly north-west and south-east, and extending as far as eye can reach in both directions, broken here and there by more prominent summits, among which the many-peaked Serbal in the extreme north, the dark *plateau massif* of Catherina or Zebir, and the bold peak of Um Shomer, opposite Tor, are especially conspicuous. This great range is the western edge of the region, which will be dealt with in this paper, and is itself a relic of a tectonic change of the first magnitude. Professor Fraas, in an eloquent passage (*Aus dem Orient*, p. 7), has referred to it 'as rising, since the beginning of things, out of the ocean, untouched by Silurian or Devonian, by Dyas or Trias, by Jura or Cretaceous; only

round the foot of it has the Red Sea drawn a crown of corals,' yet we now know that it represents the upthrow side of a magnificent fault—which at the western foot of Serbal has a throw of at least 1500 metres, the granite wall rising over 1250 metres above the plain of El Gaa, while uptilted Cretaceous marls and limestones form low hillocks, or white plateaux, at its foot (see Walther, J., *Korallenriffe der Sinaihalbinsel*, p. 452)—itself certainly post-Eocene in age, and, from comparison with the Red Sea Hills, probably only originating during the Pliocene. On this point, however, Mr. Barron, who studied the western side of the peninsula, will, no doubt, have much of interest to tell in the future. The main range, in reality, consists of a series of narrow crests, separated by but few high mountain passes, and only traversable, by heavily loaded camels, at two points, viz :—up Wadi Isleh and across the Tarfah Pass, into Wadi Nasb, and through Wadi Hebran to Wadi Solaf and Wadi Feiran—while it gradually descends in level from Zebir and Um Shomer, over 2500 metres, to about 1500 metres in Sahara, then rapidly dying away towards Ras Muhammed. It may be mentioned in passing, that the watershed but seldom agrees with the principal chain, lying to the east of it, north of Eth Thebt, while to the south most of the higher summits are on its eastern side.

If this range be crossed, and Sinai itself ascended, the view to the east is decidedly disappointing. To the north-east is seen the long white limestone wall of Jebel Gunneh running more or less east and west, and far to the east, breaking into isolated masses, ending with the fine truncated cone of Jebel El Ain. In front of and parallel to it extend the sandy plains and precipitous plateaux of sandstone, cut into deep ravines meandering in all directions, while still nearer is an apparently flat or

undulating granite plateau, out of which the Derawi Er Roghah ridge, the dark peak of Habshi, and a few lesser heights, rise as isolated projections.

To the south-west extends a mountain wall, which hides all the southern land from view, and constitutes the most important scenic feature in Eastern Sinai, extending across the country from the Central Range to the Gulf of Akaba, where it forms a precipitous ridge close to the sea-shore. This *Transverse Divide* claims special attention not only from the fact that it separates two different types of country, but also because, at least on the western side, these two regions are at very different levels, there being an abrupt fall to the south. In general the Transverse Watershed and Range are identical at all important points, the main characteristic being the gradual lowering in height from west to east.

Thus Fersh Sheikh El Arab, near the Central Range, is over 2000 metres, while Jebel Gnai, close to the Gulf of Akaba, is only 1000 metres high, the watershed itself being thrown into striking curvatures, due to causes which will shortly be considered. There are only five passes over this divide, two of which are easy, while the remainder can only be negociated by lightly loaded camels, and on these special stress is here laid, because they all have one remarkable feature in common, viz.:—*That the valleys they connect form five roughly straight lines, all parallel to one another and to the Gulf of Akaba, that is running in a direction somewhat west of south.*

What then is the origin of this structure and what characters do these depressions present?

We will at first examine two which are already to some extent outlined on the existing map, and to which the names of Um Raiyig-Shelala and Melhadge rifts have been respectively applied, these, it will be easy to show,

belong to the category of Rift Valleys, of which the Gulf of Akaba itself is a well-known and striking example, and are the effects of dynamical changes whose character, extent, and possible age may be more or less accurately determined. It may be recalled that these are not necessarily single depressions, but rather a series of basins separated by barriers, which, though higher than the main valley, are of no great altitude compared with the bordering hills.

There are, as has been said, two main longitudinal valley-systems of this kind in Eastern Sinai, both crossing and extending far north and south of the Transverse Divide, and of these the Um Raiyig-Shelala rift will first be dealt with.

In descending Wadi Nasb, the scenery of the granite region is for the most part of a fine character, bold hills scored by wild gorges filled with boulders bounding the deep and narrow ravine, which in part has a flat sandy floor, grooved only by shallow dry water-courses, while at other spots groves of tamarisk and palm, or jungles of weeds and rushes give an additional touch of beauty, and the effect of contrast is therefore very striking when, at the gates of Nasb, the way is suddenly barred by dark-green hills of softer outlines, and a valley is seen running at right angles to the previous course in a T-shaped manner. This change in the geology and topography is too marked to escape the most casual observer, but another point speedily arrests attention, a small mass of yellow sandstone being seen to rest on the opposite side of the valley against the igneous hills, which rise 600 metres above it. The interest of this occurrence is enhanced when it is found that the nearest Nubian Sandstone to the north is 25 kilometres distant, and this occurs not in the valley, but capping a granite

plateau. Turning down Wadi Shelala to the south, the same sandstone first rests on the western side, and finally blocks the way, stretching across the valley as a barrier of brilliantly variegated or dazzling white colour rising as a cliff 100 metres high, and forming the watershed at this point.

A later study of the distribution of the Nubian Sandstone showed that this relic, which has all the typical features of the rock of the main plateau to the north, has been let down for at least 700 metres, the height of the igneous hills which rise above it on both sides. Crossing the ridge, the rift is seen to continue south in an almost

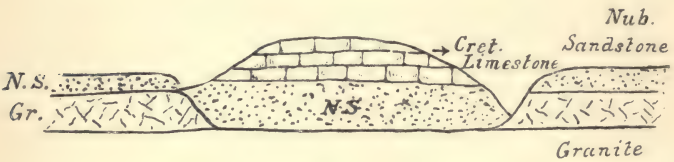

Fig. 1.

perfectly straight line, but crossed at oblique angles by transverse valleys, south of which in each case is a low pass, so that the furrow is not one continuous valley, but several, separated by low watersheds. After crossing the great drainage line of Kyd, the rift is finally cut off by Wadi El Tema, which curves round to join Wadi Kyd through Wadi El Beda.

Returning and proceeding northward from the gates of Nasb, the only striking feature at first is the steepness of the bounding walls, which rise 500 metres on each side, and it is not till the head of Um Raiyig—which continues the north trending loop of Nasb—is reached, that another point of special interest is noted, where a ridge of limestone with white sandstone at the base, almost absolutely

blocking the road and being enclosed between two walls of Nubian sandstone resting on granite, forms the hill of Um Raiyig (see fig. 1).

On the northern side of this valley the depression still continues to the foot of the Cretaceous limestone plateau, the normal boundary being the Nubian sandstone either resting on granite or occupying the whole of the low cliff—the height of the boundary walls rapidly diminishes to the north of Wadi Nasb—but in the rift itself different conditions prevail, there being the curious combination of an outlier and inlier in close proximity to one another, for on leaving Um Raiyig and proceeding northward after passing a second Cretaceous hill, we are suddenly face to face with a sharp granite crest, running north and south, and rising steeply through the surrounding sedimentaries. It is thus seen that the Shelala-Um Raiyig rift is characterised by :—

1. Its length, being about seventy-two kilometres long.

2. Its almost perfectly straight character, there being only a very slight bend where Wadi Nasb turns east, at the mouth of Um Raiyig.

3. By the steep slopes of the bounding hills throughout the greater part of its course.

4. By the occasional diversity of geological structure on both sides, especially marked where it separates the granite range of Ashara from the felsitic hills of Ferani.

5. By the letting down of younger beds along this line, so that strata have been displaced from 200 to 600 metres at least, the result being that both Cretaceous limestone and Nubian sandstone exposures occur far south of their main outcrop.

6. The presence of older granites surrounded by the younger sedimentary rocks.

Raib-Melhadge Rift. — This second rift has again a striking effect on the features of the country, and is longer than the previous one ; but does not have marked rift characters throughout its whole length, though sufficient for Russegger's map to show it as an unbroken valley extending from north of Dahab to near Nebk. The first point that strikes the traveller going from Ain El Hudera to Dahab through Wadi Ráib —erroneously named Wadi Zal by Holland—is the fact that the granite range extends far further to the north on its eastern than on its western border, a feature well brought out in Russegger's map. The eastern and western sides of the upper part of this valley are also in sharp contrast, the former being a continuous steep wall, while on the west the country is geologically far more complex, and has clearly undergone considerable disturbance. Cenomanian limestone ridges and plateaux of Nubian sandstone, the latter capping masses of granite, succeed each other in a way that shows the whole to be the result of folding and step-faulting.

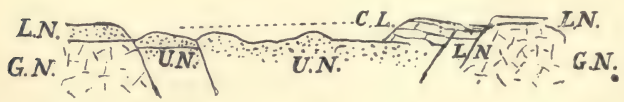

Fig. 2.

Thus, in one place, a side valley, Wadi Um Rowah, the features present are seen to be due to the breaking down of an anticlinal fold, the centre having been step-faulted. On both sides of the valley are low granite slopes—G.N. (see fig. 2)—capped by the dark-red sandstones here named Lower Nubian—L.N.—at the foot of the cliff being lower plateaux of the same rock. The centre of the valley is occupied by rocks of much younger age,

ridges of Cenomanian limestone—C.L.—and the white grits of the Upper Nubian—U.N.—being present below the level of the granite in the bounding walls. To produce this result there must have been a displacement of at least 200 metres. In the main valley itself the result is still more striking, for there Cretaceous limestones form a low ridge dipping steeply eastward towards the granite which rises immediately above it to a height of over 300 metres. Descending Wadi Raib the conditions become simpler, and the nature of its origin becomes more and more evident, the Nubian on the west giving way to granite cliffs, and the valley becoming a broad highway bounded on both sides by precipitous heights. *Yet scattered all along its course are low hills of white Nubian sandstone, and in one place Cenomanian limestone, so that the surprising result is realised, that Cretaceous fossils are collected from a limestone on both sides of which tower granite cliffs to a height of over* 500 *metres, the extent of dislocation being here at least* 700 *metres.*

There is thus no question that Wadi Raib, and its extension in the eastern loop of Wadi Nasb, is undoubtedly a rift, while its parallelism to the Um Raiyig line and the Gulf of Akaba shows them to have all been formed as part of the same movement. At the mouth of Wadi Abuksheib, where the last Nubian outlier—a fine mass 100 metres high—is met with, and beyond that point, the fissure character disappears in the low granite country, though the valleys forming the main road to Sherm run parallel to the Gulf of Akaba, and are the only ones available for camels. At the head of the Wadi Gnai, which trends north and south, the transverse divide is crossed by a low pass, from the south of which extends the long and narrow furrow of Melhadge cutting in a straight line through a dark range of metamorphic hills,

which rise on both sides to heights of from 300 to 500 metres. Those on the east are of special interest, because they form a well-defined Coast watershed, running parallel to the rift. This watershed is, however, not continuous, in the low granite country near Nebk being broken through by the two large valleys of Kyd and Um Adowi, and further south, near Letih, being only formed by a gravel terrace six metres high. As the central chain is approached, it again becomes conspicuous, attaining its maximum height in the bold projecting spur of Jebel Haimar. Holland failed to recognise this, for he speaks of finding an easy way across the head of several valleys running to the Gulf of Akaba, whereas he would have had to cross a pass in each case, had he tried to reach the sea by their means. Similarly, he has made Wadi Letih run out to the south towards Sherm, whereas it is deflected north by this watershed, and becomes a tributary of Um Adowi. The north and south trending depression can be traced as far as, and including, a portion of Wadi Letih, broken only by the insignificant transverse divide of Wadi Merari.

Of the remaining three rifts, one lying half-way between the two just mentioned, though lost in the Nubian sandstone district to the north, runs as a deep furrow through the granite plateau north of Wadi Nasb, and crossing the latter valley forms the eastern boundary of the Ferani range, while finally it bends south-east in Wadi Madsus, and cuts through the schistose hills. Here again, the depression is bounded throughout the greater part of its course by steep walls, and crossed by several low ridges, in one of which, between Wadi Um Shokeh and Abuksheib, a small inlet of Nubian sandstone is still preserved. The other two possible rifts are determined as such by their parallelism to those previously

described, but their northern extension has not been surveyed, while they are both cut off to the south by the transverse line of Wadi Kyd. These valleys lie to the west of the Shelala fracture at a far higher level than the latter, and do not contain traces of younger beds let down ; but sufficient has been said to show that a system of rifts parallel to the Gulf of Akaba has given rise to the most important longitudinal valleys in Eastern Sinai, where their presence does not seem to have been previously suspected, Hull only showing faults further to the north. Though viewed from a distance, it seems probable that rifts of similar nature are developed on a still grander scale on the eastern side of the gulf, a broad plain apparently separating two remarkably precipitous ranges of mountains.

Origin and Correlation of the East Sinai Rifts with those of Neighbouring Districts.

As the Eastern rifts form but parts of a complex system it is necessary to consider their relation to those on the western side, and in regions immediately adjoining, before their age and origin can be adequately discussed.

Glancing at the map of the Ordnance Survey, an important line is observable running close to 34° E. longitude in a north-south direction, which extends over 20′ of latitude, and is throughout traversable by baggage camels.

The explored portion of this depression opens in the north with the remarkable break of El Watiyeh, a cleft across a solid granite wall trending slightly east of north. From here Wadi El Sheikh runs south in an almost perfectly straight line, and from its continuation in Wadi

Sebaiyeh, an easy pass leads into Wadi Rahabeh, and another forms a connection with Wadi Tarfah. At the junction of the latter with Wadi Isleh, this straight character disappears, but Wadi Eth Themnin and Theman, separated by a narrow col, are not far removed from the dominant direction, and may possibly be referable to the same movement. The importance of this line lies chiefly in the fact that it is practically the separation between two differently trending systems of connected valleys, the Akaba type above mentioned being to the east, while to the west is the Suez, or N.W.-S.E. type. A study of the Ordnance map of Sinai shows that such a line is roughly outlined from Wadi Entish through Wadi Sheiger and Hargus, close to the limestone escarpment, but a still more striking example is the one which, beginning with Wadi Suwig in 29° 2′ North latitude, crosses the head of Tayiba, and forming many connected valleys, viz., Lebweh, Berrah, &c., at length reaches the granite wall bounding the Central Sinai range on the north. It is therefore of the highest interest to find that the Nagb Hawa pass, the only other entry into the Sinai region besides El Watiyeh, is precisely on the prolongation of this line, the rift being further continued in the plain of the Law, Er Rahab, the convent valley, and so over a low pass to Es Sheikh.

How completely the existence of these dislocations in the Central Sinai region were unknown is best seen by reference to a compilation of our knowledge on the subject brought together by Dr. M. Blanckenhorn, under the title 'Die Strukturlinien Syriens und des Roten Meeres,' in the Festschrift in honour of Baron von Richthofen, Berlin, 1893, where not a single one of the rifts above-mentioned is suggested.

An examination of the western coast of the Red Sea

and Arabian desert generally, by my colleague, Mr. Barron, and myself, emphasises the enormous importance of the N.W.-S.E. Suez system of rifts, these having apparently given rise not only to the abrupt western slope of Sinai and the Gulf of Suez itself, but also being the cause of the steep mountain barrier of the Red Sea hills, and of the two perfectly parallel igneous ranges—Esh, &c., and Zeit—which lie between it and the gulf. The same series of dislocations have probably given rise to longitudinal drainages in the centre of the Red Sea hills west of Abu Harba and the Gattar range, there being a road running up the centre of the northern Red Sea hills at present unexplored. Nor is it difficult in glancing at Zittel's geological map of Egypt—based on Schweinfurth's work—to recognise the general parallelism of Wadi Qena and even, in fact, of the Nile valley itself, to the dominant trend.

On the east of the north-south Es Sheikh line—practically longitude 34″ E.—as has been stated above, the Akaba type is alone present as far as our experience goes, though the faults shown by Hull north of latitude 29° N. in Eastern Sinai are indicated as absolute due north and south. Personally I am inclined to think that a re-investigation would show them really to lie somewhat east of north, parallel to the Gulf of Akaba. On the eastern side, as has already been remarked, the fine precipitous ranges of Midian visible from the Sinai side, with the broad plain which runs parallel to them, must in all probability have the same character, the Akaba rift-system being to this country what the Suez type is to Egypt. Unfortunately this portion of Arabia is not at present readily available for scientific investigation.

There is a third type of dislocation which has not yet been described, but which may nevertheless play a not

unimportant part in the structure of the peninsula. Attention has been called by Walther—'Die Korallenriffe der Sinai Halbinsel,' vol. xiv., *Abhandl. Math. Phys. Classe Konigl. Sachs. Gesell. der Wissenschaften*—basing himself on the Admiralty charts of Nares and Moresby—to the threefold character of the Red Sea, Gulf of Suez, and Gulf of Akaba, respectively, and also to the remarkably sudden increase in depth south of the Straits of Jubal, which join the Gulf of Suez and Red Sea, a similar sharp difference being noted at the mouth of the Gulf of Akaba. Here Blanckenhorn has drawn a transverse fracture south of Tiran Island, and Hull has shown similar east and west faults north of latitude 29° N. at right angles to his north and south displacements.

It is scarcely to be supposed that South-Eastern Sinai would escape taking part in movements of this nature, and, as a matter of fact, several important physical features must be directly due to their existence. Their most prominent result is probably the Transverse Divide itself, the general level of the country to the north of this physical feature being higher than that to the south. Similarly the broad spurs and transverse chains which run from the central range have had the same origin, and Jebel Zafara, south of Sherm, is undoubtedly the result of a transverse fault. In this connection, a notable feature is the *regularity* and *parallelism* of the *valley directions*, *e.g.*, other than the longitudinal rifts already mentioned. Thus, east of the main chain, 17 out of 25 valleys show a decided south-eastward trend, these all entering the Gulf of Akaba. On the other hand, six others mapped follow a north-east course, these being all situated north of the Transverse Divide, and west of the Um Raiyig-Shelala rift, against which they terminate abruptly. In fact, the following generalisation will not be far from the truth, viz., that in

the space between the divide, the Es Sheikh and the Shelala rifts, the valley directions are normally either slightly east-of-north, west-of-south, or *north-east*, while in all other parts of the peninsula the dominant valleys trend slightly east-of-north, west-of-south, or *south-east.*

It may be mentioned that on the opposite or western side of the main chain, the valleys trend north-west, south-east, or *south-west.* Many of these valleys on both sides are distinguished by the fine character of their gorges, this being especially true of the valleys north of the transverse divide, Wadis Nasb and Goura being deep fissures, on both sides of which rise precipitous hills over 600 metres high.

Principal Summary and General Statement of the Structure of Eastern Sinai.

The principal results of this investigation may thus be brought together.

1. The main mountain range from Sinai to Eth Thebt does not in general agree with the Central Watershed, but the latter is usually a short distance to the *east* of it.

2. The chief mountain line from Eth Thebt to Ras Muhammed seldom agrees with the Central Watershed, but the latter in the main lies to the *west* of it.

3. The main Sinai Peninsula mountain system consists of a series of long crests—separated by high passes—trending N.W.-S.E., and gradually lowering from 2600 metres in the north to sea-level at Ras Muhammed. The principal chain is bordered by a secondary longitudinal system, lower than the former in the northern half of the area, but, together with the east-west spurs running from it, rivalling it in the southern half. From

Wadi Hebran to Ras Muhammed only two easy passes cross the chain.

4. East of Fersh Shiekh El Arab, a Transverse system runs from west to east to the Gulf of Akaba, the general level of the country to the north of it being higher than that to the south. This is formed of a series of hill masses, at Fersh Sheikh El Arab 2100 metres high, and lowering to about 500 metres near the gulf.

5. The *Transverse Watershed* is identical with the *Transverse Chain* at most of the important points.

6. The Transverse Chain is crossed by five passes—two available for baggage camels—which have this remarkable feature in common, viz., *that the valleys they connect form five roughly straight grooves, all parallel to one another and to the Gulf of Akaba, e.g., in a direction somewhat east of north or west of south.*

7. A *Coastal Watershed* broken at two points runs close, first to the Gulf of Akaba, and then to the Central plain, until it joins the spur of Haimar running out from the main chain.

8. The Transverse Chain separates two districts:—a *Northern*, still retaining much of its original plateau character, and having an average level of over 1200 metres, except where it is cut through by deep narrow gorges; and a *Southern*, cut up into a multitude of ranges and peaks, the valleys at whose bases only reach 1000 metres at the foot of the main chain.

9. In consequence of the above, the northern mountains though absolutely higher, are relatively lower above the valleys—rarely exceeding 600 metres—than the southern ones, which commonly rise from 600 to 1200 metres above the valleys at their base.

10. Within the hill-districts, the superior hardness of igneous dykes has been the cause of a special form of

country—*dyke-country*—in which the harder dykes parallel to each other have given rise to parallel ridges, separated by shallow valleys.

11. All the main south-eastern mountain ranges are included between the above watersheds, outside being either foothills, coastal plain, or merely fringing coral reef.

12. The three principal eastward trending valleys stand in sharp contrast to each other : thus, Wadi Nasb receives almost all its drainage from the north; Wadi Kyd drains the country both to north and south ; while Wadi Um Adowi receives all its tributaries of note from the south only.

13. There are *six* north and south valleys, each consisting of deep depressions bounded by steep-sided hills, running in a straight line, and, by the presence of younger strata at their base, showing direct geological evidence of their rift origin.

14. Three dominant valley directions are noticeable. South of the Transverse Chain the valleys runs *south-east:* north of that chain and west of the Shelala rift, *north-east*, while the third system is that above-mentioned.

15. In contrast with these, on the western side of the main chain the predominant direction is north-west, south-east in the north of the peninsula, and *south-west* on the south-western side of the main chain.

General Conclusion.

The principal features of Southern Sinai have been produced by *dislocation* rather than *erosion*, fracture in three directions, either directly proved or in the highest degree probable, having determined the general structure of the country.

It is, in fact, the meeting-point of two great longitudinal rift-systems, parallel to the Gulf of Suez and Gulf of Akaba respectively, traversed by a third or Transverse type, the result being the apparently intricate maze of sharp crest and deep valley characteristic of this region.

GEOLOGY OF EASTERN SINAI.

The importance of the rift-structure in Eastern Sinai having been more specially treated in the first part of this paper, we now propose to touch upon the problems of geological interest on which the district may throw light and which at present may be considered of a controversial character. The country to which your attention is directed is that portion of the peninsula of Sinai which lies between the degrees of latitude 27° 42′ North and 29° N., and between longitude 34° East and the Gulf of Akaba. Considered in the broadest sense its geological structure is comparatively simple, the hill districts in the southern half being entirely composed of igneous and metamorphic rocks, which north of Wadi Nasb are capped by Nubian sandstone. In the neighbourhood of Ain El Hudera the latter forms a belt of low plateaux, broad plains and vertically-sided sandstone hills, extending to the foot of the escarpment of Gunneh, which itself consists of light Nubian grits capped near the summit by Cenomanian limestones. Owing to the fault and rift formation, this simple succession is considerably disturbed, the result being the production of extremely complex topographical conditions. Apart from those already mentioned the most important feature outside the hill region is the plain between Nebk and Sherm, in which

the superficial gravel deposits and coral-reefs are well displayed. North of this expanse similar reefs border the Gulf of Akaba throughout its whole length north of Nebk, forming a strip often only a few metres wide between the igneous ridge and the sea.

The geology will be considered in the following order :—

1. Pebble gravels, Travertine, &c.
2. Coral reefs.
3. Cretaceous limestones of Cenomanian age.
4. Nubian sandstone.
5. Igneous rocks, &c.

I.

1*a*.—Pebble Gravels.

Nothing will strike the observant traveller more forcibly on entering the narrow gorges in the Sinai hills than the great development of high terraces of gravel in the principal valleys, these being often over 20 metres in height, and composed either of materials of different consistency very roughly stratified, or still more often of the débris of the igneous hills mixed together in a more or less chaotic manner. Fraas was especially impressed by these occurrences, which he could only presume were the moraines left by former glaciers (though as to their age he could say nothing), an idea which is not really so far-fetched as might appear, as even at the present time snow lingers on the summits of the Sinai hills, sometimes for days together. Thus, in December 1898, when we ascended Jebel Sabbagh, it was covered with a coating of snow which had not disappeared after several days of sunshine, the temperature at the summit at mid-day barely exceeding 0° Centigrade. If the temperature here

were reduced to the same extent as it would be in Europe during the Glacial Period, a small amount of névé would have accumulated in the higher mountains, and the increased torrent-action resulting therefrom might well have been a factor in the formation of these deposits.

Distribution of the Gravels.—The facts connected with these beds are as follows :—Gravels of greater or less thickness are present in almost all the principal valleys, in a great number of the side tributaries, and especially near points where longitudinal and transverse depressions cross one another. Thus Wadi Isleh emerges into the Ga'a plain between gravel cliffs 40 metres high, the pebble beds also extending for many kilometres over the plain in the direction of Tor. Another striking case is seen where Wadi Abuksheib issues from the Ferani range, while a ridge partly bars Wadi Kyd, a little south of its junction with Wadi Melhadge.

Age of the Gravels.—The age of the gravels is best determined on the coast of the Gulf of Akaba, where they are found to overlie raised coral-reefs at Ras Atantur, while pieces of granite and schist are themselves mixed with and cemented in between the Astrean corals, which are accompanied by such typical Pleistocene or recent forms as *Laganum depressum*, *Heterocentrotus mammilatus*, and *Tridacna*. The gravels at this point are therefore not earlier than Pleistocene, a conclusion quite in accord with the results obtained for similar beds on the western side of the Red Sea.

Character of the Gravels. — The gravels above mentioned are characterised by the fact that they contain fragments of all shapes and sizes, derived from the surrounding hills, which are embedded in a sandy matrix consisting of material of the same

derivation, the source being thus strictly local. With regard to the question of their origin, it is only possible to suggest considerations, the theory which commends itself to the writer involving a combination of two circumstances, viz., the earth-movements of which the region shows such abundant evidence, and a greater rainfall.

The earth-movements might very readily have resulted in temporary ponding back of the mountain torrents, when it is recalled that the greater part of south-eastern Sinai is even now almost a closed system, bounded on three sides by mountainous watersheds, only one of which is broken through by two valleys. With regard to the question of greater rainfall, it need only be noted that at the present day the storms, though frequent in winter, are of short duration, and the resulting torrents are active in the work of erosion, rather than of deposition, these being chiefly engaged in filling the smaller valleys with confused masses of huge boulders, such as will be familiar to every traveller who has climbed the mountains of the peninsula.

But one of the most striking features connected with these gravel plateaux, is the perfectly flat nature of their upper surface, even in the upland wadies, a character quite inconsistent with their having been produced by rushing torrents, but in accordance with the hypothesis of their formation in ponded-back lakes, or marine fjords. The apparent absence of any marine shells renders it probable that the detrital beds of the central portion of Sinai are due to deposition of the material derived from the surrounding hills in lakes, rather than to their accumulation in arms of the sea. Whatever theory may finally gain acceptance must take account of their extensive distribution, and the height at which they are now found, they sometimes being 1200 metres above sea-level.

1*b*.—Manganiferous Pebble Gravels.

While the majority of the bays of the Akaba coast are broad inlets of the sea, running into the land between the yellowish-white limestone cliffs of the raised coral series, Sherm is at once distinguished by the red and black colouring of the scarp commanding the bay to the west and south. This exceptional appearance is due to the presence of a conglomerate, whose constituents are *cemented by the hydrous black oxide of manganese*, psilomelane, in places as much as four metres thick, while underneath are beds coloured red by ferruginous ochre. These gravels are closely connected with a core of red granite, stopping abruptly where the latter is no longer exposed at the surface to the north, with the result that the northern cliff is of a totally different character, consisting of coral-reef, forming a cap to sand-rock of varied tints. The manganiferous gravels, too, only seem to be connected with and overlie the granite at the point where the latter faces the sea, extending but a short distance up the valleys, and not being found south of the transverse chain of Zafara. It is interesting to note that the Austrian ss. *Pola* found manganiferous deposits forming on the floor of the Gulf of Akaba itself, a fact which lends support to the view that these gravels are of marine origin, though no organic remains have been noted in them.

1*c*.—Oolitic Valley Deposits.

Walther, J. ('Die Korallenriffe der Sinaihalbinsel,' Bd. xiv.; *Abhandl. math. phys. Königl. Sachs. Gesellschaft der Wissenchaften*, pp. 481–484), calls attention to the fact, that near Suez, and especially on the border of the

Tyh desert, he found oolitic grains, while he had nowhere noted oolitic rocks, either in Sinai or in the Arabian Desert. From his examination he concludes that these grains, met with especially at the mouth of Wadi Dehese, are really a recent formation *in statu nascendi.* A closer examination showed him that these consisted of quartz-grains enclosed in a calcareous layer, and that when several zones were present, there was a darker band between the inner dark yellow, and outer clear shell of calcite. Amongst the minerals noted as nuclei, were felspar, garnet, magnetite, and fragments of Foraminifera. His conclusion is that the mineral grains come from the desert, and have been carried by land-winds into the shallow sea, where various small animals would play their part in assisting the formation of the calcareous coatings.

These interesting observations can now be extended, as an oolitic rock of this very nature is most extensively developed among the hills north of Ras Muhammed, where it forms a striking light-coloured calcareous sand-rock, bounding Wadi Hashubi, and almost filling the small tributary valleys, which are reduced in many cases to narrow cañon-like ravines. Walther has mapped this as Dünensandstein of Hashubi.

The facts noted in connection with it are :—

1. The sand-rock consists of quartz and orthoclase grains, similar to those of the wind-blown sand in the neighbourhood, cemented by carbonate of lime, which in many places surrounds them in a series of concentric coats.

2. These strata dip in every direction, being often plastered against the sides of the hills, or forming horizontal beds cut down vertically in the gullies. In places they show *traces of ripple-marking, very fine sun-cracks,* and abundant long tubular cavities.

In the lower part of Wadi Hashubi they are very thick and horizontal, in some places being strongly current-bedded and containing lenticular masses of pebbles, the dip they show when overlying the surface of the igneous rock being probably due to slipping of once horizontal beds worn away from below, for the sand-rock has a peculiar habit of weathering internally, a thin external wall pierced by small holes only masking a larger internal cavity.

Similar strata were found to be present in the small side valleys of the lower igneous ranges west of Sherm, but detrital material is more abundant than in Hashubi, pebbles of granite over 10 cm. in diameter being present. An interesting feature here too is the height at which the sand-rock occurs, a typical example on the pass between Jebels Abuzag and Hedemia being at 696 *metres above sea-level.*

At the head of the valley running from this point the cañon structure is strikingly displayed, these light-coloured beds forming almost vertical battlemented walls about 45 metres high (pierced with holes, mostly of semi-circular form), overhanging a sandy plateau, which is again cut into by narrow, winding ravines, themselves carried down deeply in the underlying granite.

The origin of this remarkable deposit is again wrapped in some obscurity, the natural view that it is of marine derivation not being absolutely confirmed by the discovery of any marine organisms. Nevertheless, the results obtained by Walther are in favour of this hypothesis, which would demand a differential movement of no less than 700 metres in the southern end of the peninsula during comparatively recent times, a result which, though startling, is in accord with evidence from neighbouring regions.

1*d*.—Gravels Cemented by Calcite.

As though the difficulties connected with the superficial deposits were not sufficient, there occur in the lower part of Wadi Nasb, and especially close to its junction with Wadi Abuksheib, certain terraces resting on Nubian sandstone and granite, containing boulders of syenite, biotite-gneiss, felsite, and red granite (often over one metre in diameter), *cemented together by crystalline calcite* in the form of well-developed scalenohedral crystals. The question of the source of the calcite which has acted as the cementing substance rises in connection with other beds which appear in most unexpected places, viz. :—

1*e*.—Travertine and Conglomerate Cemented by Travertine.

The igneous hills are probably the last place in which one would expect to find deposits of the above character, but, subsequent to the first discovery by Mr. Skill of typical calcareous travertine of spongy texture lining the walls of a granite gully, or couloir, we frequently met with it in out-of-the-way valleys, either in similar positions or at the foot of precipitous steps, which would be waterfalls in time of rain. In the latter cases a conglomerate of igneous pebbles has been produced, the cementing substance being compact carbonate of lime, while in a fine example occurring at the water-hole in Wadi Um Shokeh, over 500 metres above sea-level, remains of the conglomerate cling to the walls of the ravine at the upper level of the slope. From whence then would the calcite be forthcoming for the formation of these beds? Three possible sources at once suggest themselves: (1) Cretaceous

limestones have been let down in Wadi Raib and are abundant at its head, so that the torrents might bring down bicarbonate in solution. (2) There is, however, no evidence of the presence of these limestones in many places where travertine is of common occurrence, so we are driven to a second local cause, viz., the production of calcite by the decomposition of the felspathic portion of the diabase dykes. How far this is active can only be proved by an analysis of selected torrent waters, a work which must be undertaken by future travellers. (3) There is, finally, the possibility already suggested that there has been a marine depression to the extent of 700 metres, which would probably bring all the valleys in which travertine has been noted beneath sea-level. If this were so, no further search need be made for the source of the carbonate of lime.

Summary.

It will thus be seen that the gravels, &c., suggest considerable changes of level and different conditions from those now prevailing, erosion at present exceeding deposition. The theoretical deductions helping to explain their presence may be here briefly recalled :—

1. In South-eastern Sinai earth-movements have produced three high watershed lines, only one of which is now broken through. If these were formed at the same period, all the water draining into the basin enclosed by them would collect to form narrow lakes. This would account for :—

   (*a*) The flat character of the plateaux.
   (*b*) The absence of marine organisms.

2. A marine depression resulting in the invasion of the

sea, and amounting to at least 700 metres, is also suggested, and would best account for :—

(*c*) The oolitic beds of Wadi Hashubi.
(*d*) The manganiferous gravels of Sherm.
(*e*) The travertines of the higher valleys.
(*f*) The gravels of Nasb, cemented by calcite.

The flat character of the plateaux is also not excluded by this hypothesis.

3. A subsequent elevation accompanied by earth-movements, resulting in the uptilting of coral-reefs, brought the formation of these special features to a close, the gravels from the hills being now distributed irregularly over the surface, in places overlying the oolite beds, and being interbedded with Pleistocene coral reefs.

II.

CORAL REEFS AND RAISED BEACHES.

At the commencement of the above-mentioned paper of Professor Walther (*loc. cit.*, p. 440) occurs the following statement : 'The shore boundary rich in corals is *entirely wanting* in the Gulf of Akaba. Only to the east of Ras Muhammed small fringing reefs (Schirmriffe) are found against the steep slopes of the cliffs, and more extended reefs of younger Tertiary age are also to be observed. In the main gulf there are also small coral aggregations at the mouth of Wadi Nasb and Wadi Ghasaleh. Immediately beyond the shore, depths of 60–150 fathoms have been noted, while at the exit of the Tiran Straits, bottom was only touched at 594 fathoms. Therefore the

Gulf of Akaba presents itself as a deep rift, bounded by steep slopes, and poor in reefs.'

Somewhat of the same impression for the southern end is left by a study of Moresby's Admiralty chart, which was probably followed by Professor Walther, who does not appear to have visited the Gulf of Akaba himself. As a result of the present expedition, the above-expressed view must be abandoned, Mr. Skill having now mapped continuous reef from Dahab to Ras Muhammed wherever it was possible to get a view of the shore line, it forming an almost unbroken fringe, which renders approach to the coast dangerous for even small boats, except at a few localities, such as Sherm, Dahab, and Nebk.

The Fringing Reef and Lower Coral Series.

The Fringing Reef is in reality one of the most conspicuous features of the gulf, extending from the shore as a white, narrow, usually submarine, ledge, its outer border being marked by a long line of surf, beyond which the water is of intense dark blue colour, due to its great depths. Closely associated with it, but at a higher level, is a second reef, which to the north forms isolated terraces up to 25 metres high, standing only a little way back from the water's edge. The former is naturally the one which attracts the attention of the zoologist, but the latter is also characterised by a very rich and varied fauna. North of Nebk this 'Lower Coral Series' is only conspicuous at three points :—

1. The northern end of Dahab peninsula.

2. In one of the mountain bays to the south of Dahab, and

3. Forming the point of Ras Atantur, at the northern end of the sea-plain.

South of Nebk the terraces increase in thickness and height above sea-level, and extend with but few breaks to the neighbourhood of Ras Muhammed. The age of this series presents no difficulty, as the limestone is crowded in its lower part with such typical Pleistocene forms as the flattened spines of *Heterocentrotus mammilatus*, *Laganum depressum*, also *Tridacna*, *Nullipores*, &c., *Cœloria*, and *Fungia*. At both Dahab and Ras Atantur the uppermost layer is a compact limestone, consisting of closely aggregated Astræan corals, but in the former case the base-rock is composed of granitic gravels, which near the junction are full of large boulders of the igneous rock, while at the latter locality the limestones rest on soft salty marls, containing a band of broken oysters.

South of Nebk the contained fauna vies in richness with that obtained on the western shores of the Red Sea, where beds of identical age yielded several hundred species. An especial point is the abundance and size of the Gasteropoda, including a characteristic striped *Strombus* (*S. fasciatus*) and large Terebras.

Raised Beaches.—Closely associated with the limestones of the 'Lower Coral Series' are the Raised Beaches which line the shore wherever the cliffs do not rise directly from the sea. Many of the shells are identical with those found in the neighbouring terraces, while where the coasts are rocky, shells of large *Pteroceras bryonia* and *Tridacna*, associated with many beautiful sea-urchins, are crowded amongst the boulders. This is especially the case between Nebk and Dahab, where in addition a thin ledge of raised coral-reef, flanking the coast, forms a flat natural road, which was very useful when mapping the hills, here dipping steeply towards the gulf. The summit of this raised reef is formed of a pavement of smoothed and polished blocks

of gneiss and hornblende-rock cemented together by white calcareous material and corals, the whole forming a smooth surface, which is an admirable track wherever developed. This raised reef containing Astræan corals in abundance may be equally included in the ' Lower Coral Series.'

Upper Coral Limestone or Older Fossil Reef of Walther.

South of Nebk a second coral reef flanks and apparently overlies the lower one, but is evidently of older date, the coral having undergone much alteration. This is the same rock as the one described by Walther (*loc. cit.*, p. 494), and of which he has given a very good figure when representing the probable relations of the beds in his No. 5, fig. 20, p. 465.

The characteristics of this bed are its extremely porous nature, recalling in this respect the cavernous character of a modern reef, but with this difference, that in the older reef the cavities are filled up to a certain extent with shells and broken calcareous fragments. It differs, too, from the younger reef in its peculiar dirty-brown colour, due in the main to the dolomitic alteration which has been so frequently noted in connection with raised coral.

Owing to its perfect horizontality, a flat plateau has been produced which extends a long distance between the sea and the plain north of Sherm, unbroken by the slightest elevation. South of Sherm it is less conspicuous, though, as will be seen when the geological map near Ras Muhammed is published, by no means uncommon, and finally at the cape itself it attains a maximum height of 90 metres, this being at a very different level from that on the Gulf of Suez, where Walther gives 230 metres as its height at Jebel Hammam Musa, north of Tor.

At present it is not possible to give a very clear idea of the fauna of these beds, but the corals, which are still in many cases well preserved, at least externally, agree closely with those described from the higher reefs on the west coast of the Red Sea, and include not only typical Astræan forms, but also abundant mœandroid specimens here provisionally referred to *Cœloria*. The most important genus in this upper Coral Limestone is probably *Orbicella*.

The best sections are those seen immediately north of Sherm, and from these the following typical succession may be given, beginning from above :—

1. Cavernous Calcareous Limestone (Older Coral Reef) which has undergone dolomitic alteration, containing *Orbicella*, and three other Astræan types, *Cœloria*, *Anadara*, large gasteropod casts, Nullipores. Thickness one metre.

2. Coral and Millepore limestone, in places forming a small vertical cliff, and to the east changing into a compact white chalk, in which are casts of large bivalves, *Venus reticulata*. Four metres.

3. Oyster and Pecten bed, full of oysters, *Pecten*, *Laganum depressum*, the small *Echinus verruculatus*, only previously recorded from Mauritius (according to Professor Gregory).

4. Brown and greenish salty marls.

These are *apparently* succeeded by

5. Nullipore rock.

6. Limestone with large ornate *Venus*, *Cyprœa*, *Tridacna*, and a large *Trochus*.

7. Limestone rich in Gasteropoda, &c., including the striped *Strombus*, *Conus*, *Dentalium*, sea-urchin spines (*Heterocentrotus*), *Goniastræa*, and several species of *Fungia*.

8. This limestone is separated from the sea-shore by

two beaches, the higher consisting of larger spineless specimens of *Echinometra lucunter*, associated with *Haliotis*, while the lower consists of small varieties of the same sea-urchin still covered with their spines.

Nos. 1 to 4 include the Older Coral Reef series, the latter being the oldest member and No. 1 the youngest.

Nos. 5 to 7 form a second terrace, and compose the Younger Coral Reef series, No. 7 being younger than No. 1, but older than 6 and 7. Finally No. 8 is quite recent.

South of Aad Bay a still older set of beds make their appearance, which differ from those previously described in being tilted at high angles, in most cases standing well back from the sea, and having undergone extreme alteration. South-west of Aad Bay they form a small, but conspicuous hill, rising 52 metres above the Upper Terrace (that of the older Coral Reef) in which the beds of semi-crystalline limestone are dipping 4° south-east and still show traces of coral. South of Jebel Zafara, a conspicuous east and west ridge near Sherm (well shown in a photograph taken by Professor Natterer of the *Pola*), these are still better developed, forming a series of yellow hills lying close to the junction with the igneous rocks, and rising nearly 200 metres above the sea. Here the beds have been tilted to an extraordinary extent, in some cases dipping from 30° to 60° east, and being apparently connected with a longitudinal fault of importance. In these the whole general appearance recalls the altered coral reefs, and they still contain oysters and casts of *Pecten*, but at present the evidence is not sufficient to establish whether they are Pleistocene, or pre-Pleistocene in age, a point obviously important in connection with the discussion of the earth-movements in this region.

Having thus dealt with such details as are necessary, special stress may be laid on the following general points :—

The coral reefs of the Gulf of Akaba show the following distribution :—South of Aad Bay and Sherm there are conspicuous tilted coral hills, and two horizontal terraces representing Pleistocene reefs of different age. Going north, between Nebk and Aad Bay, the two latter alone are represented, the tilted beds being absent. Finally, north of Nebk, only the Lower Terrace, or Younger Coral Reef, and the recent fringing reefs are observed, there being no trace of raised coral beds high on the sides of the hills such as have been noted on the Red Sea coast. In other words, *the Older Reefs are only present at the southern end of the Gulf of Akaba.*

Coral Reefs formed in a region of elevation.—From what has been said above, it is obvious that only one conclusion can be arrived at, viz., *that the coral reefs of the whole of this region have been formed during a movement of elevation, the oldest ones being at the same time the highest, while the upper terrace is composed of beds which are older than those forming the lower terrace.* This elevation is directly proved from the present height of the coral reef to be at least 200 metres in amount, and the question arises, is it still being continued ? For the Gulf of Akaba, the answer is perhaps a slight negative, the chief grounds for this conclusion being the discovery made by Walther, that a reef, probably dead judging from its striking white colour, exists under the present submarine living one, suggesting a local depression of about 6 metres, and the same idea occurred to me as an explanation of the fact that so many inlets from the gulf are only intrusions of the sea up the mouths of the valleys.

Thus Ghazlani, Sherm, Aad, and Nasb Bays are all of

this nature. The only other alternative would be that the material brought down by rains from the hills had had an unfavourable effect on the growth of the reefs; but against this theory many objections can be urged. *It therefore appears probable that a small local depression* (6 metres according to Walther) *is at present taking place in the Gulf of Akaba*, the latter differing in this respect from neighbouring regions.

It will now be of general interest to take up the five questions which Walther set himself, and see how far the Gulf of Akaba leads us to agree with or differ from his conclusions.

1. To what thickness may coral reefs attain? In this respect our agreement with Professor Walther is absolute, viz., *that a coral reef does not attain any great thickness.* Thus to the north of Sherm a bed mainly composed of corals just exceeds 1 metre in thickness, and if the underlying limestones, Pecten beds, &c. be taken into account, 6 metres is the maximum noted. Presumably, Walther has included these beds also when he gives the thickness of the younger reef at Ras Muhammed as 9 metres, and the older at about 7 metres, while the recent reef does not exceed 3 metres. The greatest thickness of raised limestone observed on the gulf is 54 metres, viz., in the section described on page 14, yet an examination of the component rocks will show that in all these beds true coral reefs are of comparatively rare occurrence, strata composed of millepores, calcareous algæ, and broken fragments of sea-urchins, mixed with innumerable gasteropoda, being more conspicuous elements.

2. What is the basis of a coral reef? On this point our results differ to a certain extent, and especially in one particular to be referred to later. The upraised reefs give good opportunities in many cases for a close study of the

base on which rests the limestone of the coral series, and it is seen that the latter varies very widely at different localities. Thus, at Dahab, it consists of granite gravels, which near the junction are full of large boulders of the igneous rocks, while at Atantur only soft, salty marls are visible beneath the coral limestone. From Dahab to Atantur no base rock has been observed, but the reef projects directly from the hills composed of gneisses and hornblende-granite, immediately outside which the sea sinks to great depths, so that it is probable that the coral has grown directly on the detrital materials derived from the neighbouring mountains. Immediately north of Sherm, a junction is again beautifully displayed, the coral reef resting unconformably and horizontally on the underlying sand rock (probably Nubian sandstone) which here dips at four degrees, while elsewhere it overlies gypseous sand-rock and marl. Again, near Hedemia Bay, our field notes read, 'The road taken lay among the coral-reef series, which forms a thin covering to sandy beds with red ferruginous bands and lines of pebbles dipping four degrees south-east, while in the small valleys a flaggy rock of granitic materials also appears at the base, having the same dip.' Walther, after a careful discussion of the relations of the base to the coral reef (*loc. cit.*, pp. 496, 498), answers the above questions as follows :—'The fossil, and probably also the living coral reefs of the Sinai peninsula are based on the outcrops (Schichten-kopfen) of compact *sedimentary* [the italics are ours] rock, they are wanting on the softer and more crumbly coast-rocks of the Sinai peninsula.' The discussion and conclusion both suggest that the igneous rocks are of little use as bases for reef formation, but if this be the right interpretation of Professor Walther's view, strong exception must be taken here to such a limitation,

which would render it impossible to account for the existence of the fringing reef bordering the hills south of Dahab. Indeed, elsewhere, viz., on the western side of the Red Sea, on the eastern border of Jebel Esh, where coral-reef is tilted at over 20° all along the sides of the igneous hills, the limestone is only separated from the underlying granite by a thin granitic conglomerate, and near Qosseir there is scarcely any detrital material between the diabases and the coral bed plastered against them. Instead, therefore, of having any limitation, we conclude that, in general, *the deposition of a coral reef is practically independent of the nature of the rock forming its base.* Our own experience now includes red granite, diabase, sand-rock, and marls, amongst the basal members, with gneiss and hornblende-granite as highly probable.

3. What rôle does detrital filling material play in the living reef? Practically, there is nothing to add to Professor Walther's statements. He very justly points out the easily breakable character of the madrepores and the importance of the calcareous algæ, such as *Lithothamnium* and *Lithophyllum* in binding together the broken fragments, or forming a crust over a sandy floor, on which basis a coral reef can be built up. It may here merely be further stated that attention is also called by the above writer to the importance of crabs in breaking up the organic remains, producing the fine calcareous sand, which fills the cavities between the dying coral-stems, and in addition may be noted the abundance of the red encrusting foraminifer *Polytrema*, the fragments on the shores of the gulf being in places completely overgrown by this bright-coloured organism.

4. What alterations do the reef-sediments undergo when they finally rise out of the water?

The effects of change are only too quickly visible, the

brilliant-coloured living reef being replaced nearer the shore by the dead-white surface so familiar to all students of coral deposits. As the coral limestones are examined the observer cannot fail to be struck with the absence of many forms, which on the sea-shore itself seem to be the principal members of the fauna. In vain will traces of crabs be sought for, though on the beach they occur by thousands, while the beautiful *Phyllocanthus*, the large *Heterocentrotus*, and many other fine sea-urchins, are only represented by spines in varying degrees of preservation. Though Ophiurids fill every pool, they leave no record behind them, and if it were not for the abundance of Mollusca and the Corals, but little would be left to recall the life and movement of the tropical marine fauna.

No doubt this disappearance has in large measure to do with the *instability* of the *aragonite* composing the skeletons of many of the above-mentioned animals, while in addition, in the higher parts of the reef, the progressive formation of casts from shells of *Strombus*, &c., can be watched in all its various stages. But this is not the only change to which a coral reef is subject, and the upper terrace has lost its whiteness and taken on a dusty grey appearance, which is indicative of the further chemical alteration, viz., *the passage from limestone to dolomite* by the *increase* in *magnesia*.

This change is too well known to require further pressing here, and Walther's analyses show how far it has advanced in some of the reefs. As a result the coral structure has become practically obliterated, and in the older reefs, where the correct identification of the fossil contents is of first importance, the collector finds only unidentifiable casts, or at most the last traces of calices and septa.

5. The final question—What alteration in form and

extension of reefs has taken place in the course of geological history?—has been answered as far as possible previously, but it may be here repeated, that apart from the tilted limestones whose age still remains uncertain, the two horizontal raised reefs do not appear to be older than the Pleistocene, north of Nebk the Pleistocene terraces, but little above sea-level, being alone present.

Cretaceous Limestones and Nubian Sandstone.

As has already been stated, the older sedimentary strata only appears in the northern part of the area under discussion, but these in the neighbourhood of Ain El Hudera give rise to very varied scenic effects.

The main divisions recognised beginning from above are as follows:—

1. Cretaceous limestones, of considerable thickness, somewhat poor in fossils, forming the summit of the plateau of Gunneh, which terminates in a steep escarpment facing southward, and they also play a similar part in the various outliers let down in the rift valleys, as described in the paper dealing with those occurrences.

2. Underneath the limestones a highly characteristic striped series of green marls, &c., is always present, which contains typical Cenomanian fossils, such as *Hemiaster cubicus*, *Pseudodiadema variolare*, and *Heterodiadema libycum*.

3. The marls themselves are only the surface capping to a thick series of white sands, which, having been cut by vertical furrows to their very base, now rise as isolated masses over 100 metres high, bordered on all sides by

vertical walls, and, owing to the softness of the material, far more dangerous to climb than the higher igneous hills to the south.

4. These are based on broad, low, smooth plateaux, in general dipping gently northward, due to a hard ferruginous bed overlying variously coloured ferruginous sandstones, which themselves have been deposited on a planed-down surface of granite.

Owing to the existence of the Raib rift, these strata are separated from the sea by the long range of granite which runs from Noweiba to Dahab, and similarly granite hills rise from amongst them, or tongue into them in an apparently bewildering manner when first observed, though after a time it is possible to trace the various faults and folds which have caused the complexity.

One or two special examples will further illustrate these points: On ascending the northern bend of Wadi Nasb and Wadi Um Raiyig, which continues it to the northward, the valley is suddenly narrowed by a tongue of granite projecting from the eastern cliff, and only widens out again behind it to be once more completely barred. The nature of the obstruction is interesting, for while the side wall of the valley consists of granite, on which rests the flat-topped ferruginous sandstone (No. 4) above mentioned, the barrier itself is of very different composition, its base consisting of the fine white sand-rock (No. 3), immediately succeeded by green and closely banded marls, almost entirely consisting of oysters and mytiloid forms (probably *Ostrea africana*). Above these follows a compact limestone about 6 metres thick, crowded with casts of a large *Tylostoma*-like univalve, and in the downwash a small variety of *Hemiaster cubicus* is abundant, also *Tylostoma* and flat bivalves, and large forms of *Cucullœa* are also found in the upper layers.

The total thickness of these striped beds is 18 metres, the summit being formed of non-fossiliferous bedded limestones. Practically every section of the striped series examined in this region yielded these *Tylostomas* and *Hemiaster cubicus*. Many local variations are, however, noticeable ; thus, in an outlier north of Um Raiyig, small red *Nucleolites* and *Heterodiadema libycum* occurred in hundreds weathered out at one spot on the hill, and in most of the exposures a large Exogyra bed is conspicuous near their base.

The escarpment of Jebel Gunneh also gave a good section for thickness, this being determined as follows :—

	Metres.
Compact limestones, from which the fossils are difficult to obtain in recognisable form, provisionally referred to Cenomanian	100
Marls and limestones with typical Cenomanian fauna, including large *Exogyra* and *Tylostoma*, *Hemiaster cubicus*, *Heterodiadema libycum* ...	20
White sands and ferruginous Nubian sandstone	207
Total thickness	327

Very briefly, then, the lessons suggested by the sedimentary series at this point are as follows :—

1. The granite was planed down and the Nubian sandstone deposited regularly on the plain of marine denudation. In this region there is no case of the dykes (so abundant in the granite) passing up into the sandstone, they being cut off abruptly at the point of junction. The sandstone at the base, brightly-coloured, ferruginous, and false-bedded, passes up into a great thickness of white, friable sands, themselves underlying marls and limestones

containing a Cenomanian fauna which belongs to Zittel's Africano-Syrian Series, since Mr. Beadnell's discovery of a group of Cenomanian fossils in Baharia, shown to have had an enormous extension north of latitude 28° north. It will be seen from the above remarks that the Carboniferous limestone has died out to the east, and there is no proof whatever that any of the Ain el Hudera sandstone is Carboniferous, but, as in the whole 200 metres no fossil has been obtained, no decisive answer can be given on this point. Similarly the uppermost Cretaceous beds in Jebbel Gunneh have not yielded a fauna capable of closer identification.

Attention has been called in the first part of this paper to the remarkable extension southward of the Cretaceous limestones and Nubian sandstones owing to the faulting of the peninsula, so that Exogyras of the Cenomanian series can be collected in Wadi Raib from low hills, on both sides of which rise steep walls of granite 500 metres high, while similarly the Nubian sandstone of the Shelala Pass is dominated by ranges whose summits are 600 metres above the valley.

The history of South-eastern Sinai since and including Cretaceous times thus presents many gaps, for records from the Eocene and Miocene, and possibly Pliocene as well, are absent, yet sufficient remains to show that during the Cenomanian period began the depression first marked by sandstones and sandrock, and gradually succeeded by the fossiliferous marls and limestones.

The dip and present position of the Nubian beds would be sufficient to show that these strata once extended over the whole of the present igneous mountain region, even if they were not found let down in the heart of the mountains, and flanking the plain between Nebk and Ras Muhammed, where sandy layers, sometimes containing the

quartzite pebbles typical of the Nubian, form the basis of the superincumbent coral reefs. Only with the Pliocene or Pleistocene is the record once more resumed, but no longer as a story of quiet depression and deposition, but one of storm and stress, of mountain upheaval and gigantic fracture, producing valleys cutting deep into the plateaux, and giving rise to a topographical puzzle, which we hope partly to have elucidated, and which will be more clearly understood when the map prepared by Mr. Skill shall have been published, geologically coloured along the lines of our original field-sheets.

Resulting from these movements the Gulf of Akaba came into existence, and connection was set up with the Indian Ocean by way of the Red Sea, the depressions and elevations produced being witnessed to by the coral reefs and gravels described in the previous pages.

ADDITIONAL NOTES.

The Igneous Rocks of Eastern Sinai.

The Peninsula of Sinai has been justly described by Captain H. S. Palmer, as follows :—('Ordnance Survey of Peninsula of Sinai,' Part 1, Chapter 1, page 17).—'The Peninsula of Sinai, or at any rate the greater part of it, is in reality one of the most mountainous and intricate regions on the face of the earth : sand is a feature seldom met with, plains are rather the exception than the rule, the roads are often steep and rugged, and wind for the most part through a labyrinth of narrow rock-bound valleys. It is a desert, certainly, in the fullest sense of the word, but a desert of rock, gravel, and boulder, of

gaunt peaks, dreary ridges, and arid valleys and plateaux, the whole forming a scene of stern desolation which fully merits its description as the "great and terrible wilderness." So far from there being nothing to survey, the topographer may well shrink from the task of delineating its countless intricacies.' These words are no exaggeration, and a few figures tell the same tale, for during a period of seven months, Mr. Skill and the writer ascended over 54,000 metres in the course of the daily work (this excluding all minor stations), the average height of the summits ascended for over four months and a half being 450 metres per day.

In addition to the mere surface diversity, the geological structure plays a great part in producing scenic variation, granite ranges rising in abrupt precipice or smooth-sided slopes above deep ravines, and breaking up into sharp peaks or thin saw-like crests. Elsewhere, as in the Ferani range, felsites have produced high plateaux, only slightly undulating at the summit, but terminating on all sides in frowning cliffs, which tower above rock-strewn and sinuous boulder valleys, during times of storm scoured by rushing torrents and foaming cascades. Standing on the central summit of Abu Mesud and looking towards the Gulf of Akaba, the eye rests on a dark confused mass of hills mainly composed of schists contrasting strongly with the granite which surrounds them on every side, one of the most arid regions in the whole peninsula—barren ridges dominating sinuous gorges, where only a scanty herbage finds a foothold.

THE IMPORTANCE OF DYKES AS DETERMINING SCENERY, &C.—The traveller in Sinai, and especially one who has to examine it closely, is almost immediately struck with the remarkable banding of the whole country by variously coloured dykes, which seam the mountains,

running over the highest peaks, and preserving a perfect parallelism to each other, which persists over many kilometres. Thus, even before Wadi Isleh is entered, the small ridges which cluster at the foot of the higher mountains are all seen to owe their origin to dykes, mainly running in a N.N.E. and S.S.W. direction, while in the high ranges of Shiddok and Emlaha, the red and dark bands pass over the main crest. Our own observations show that these veins practically extend throughout the whole igneous region over many kilometres, without any perceptible break in their continuity, and by their superior hardness determine the directions of many ranges.

When composed of basic rocks, they often produce gullies, which not infrequently form the only road by which some of the steeper scarps can be ascended.

These dykes are of almost every petrographical variety, from the coarse quartz-felsites and fine-grained felsites, which are more commonly found in the granitic regions, to the dark dolerites and spheroidal diabases which, in the metamorphic districts, are sometimes so crowded as to completely mask the schistose rocks enclosed between them. They are clearly the youngest members of the igneous series, as every other type of rock has been penetrated by them, but as has been previously remarked, none of them have been noted passing into the Nubian Sandstone, which rests upon a plane cutting them off abruptly. Thus, in Eastern Sinai, at any rate, all the dykes appear to be Pre-Cenomanian, and, judging from the neighbouring regions, probably Pre-Carboniferous as well.

Duplicate System of Dykes.—While the general trend of the main system of dykes is N.N.E. and S.S.W., there is frequently a second system, practically at right angles, which in some cases shows marked differences,

though these are not sufficiently constant to establish any general rule. Thus in the slopes of Abuksheib, above Wadi Nasb, a N.W.-S.E. running group consists of basic dykes which have shifted the acid and basic members of the principal series, and is consequently of younger age. At other times two cross each other, giving rise to X-shaped forms such as are developed in Wadi Letih, or to an interlacing mass of dark veins, there being a beautiful example of this class in the hills near Dahab.

For further remarks see Holland, 'Ordnance Survey,' p. 220, Fraas, and many other writers.

The dykes vary considerably in thickness, sometimes being only a few centimetres wide, while more commonly they vary from the ten metre bands of Isleh and Beidha to the huge green dyke, 100 metres broad, which runs steeply up the granite slope opposite Jebel Jeraimdeh, near Dahab.

It is here only possible to mention in addition that in the broadest outlines the Sinai Hills resemble the mountains on the opposite side of the Red Sea, though the fundamental rocks of the central axis of the peninsula are *granitoid gneiss* and *hornblende-granite*, not the *red granite* which forms the main summits in the Red Sea Hills. The latter is, however, also widely distributed in the peninsula, especially in its northern half, and in places it has been found possible to map the line of junction of the two types. Of special interest are beds of andesite, tuff, and agglomerate, which form some of the principal summits capping the granite and gneiss. This 'Volcanic Series,' which recalls that of Jebel Dokhan, crowns the high ranges of Katherina, Abu Mesud, and Ferani, and is in general only a surface covering underlaid and intruded into by the granites, &c. Closely associated with it is a *Metamorphic* type, developed in a broad

region embracing many of the lower hills near the Gulf of Akaba between Dahab and Nebk, and giving rise to a series of steep-sided ranges enclosing deep, barren, desolate, and waterless valleys. On the west above Wadi Kyd these rocks are mainly spotted slates, 'Knoten-schiefer,' containing large quartz pebbles which have been recemented, and compact yellowish-grey siliceous varieties. Further to the east they are replaced by true dark-green chlorite-—and hornblendic—schists, pierced near the Gulf of Akaba by innumerable dykes of dolerite, and flanked towards the sea by a band of grey and red gneiss, while nothing is more striking than the abrupt junction between the granite and schists where the two meet in the hills north of Nebk.

It is impossible here to discuss the numerous questions connected with regional and contact metamorphism on which Sinai may help to throw light, as there has been as yet little opportunity to compare the results noted with those recorded in the literature already collected on this subject. Some of the most striking special features observed are as follows :—

(*a*) In Wadi Um Gerat, a short distance from the junction of the granitoid gneiss and schists, true gneisses are developed on a magnificent scale, occurring, however, in bands only a few metres thick, alternating with a finely developed deep-green or black hornblende-schist. This highly foliated structure seems to be purely local, the gneissose character being usually somewhat obscure, though clearly marked on a smaller scale at many points, *e.g.*, in Wadi Isleh.

(*b*) In Wadi El Tema the junction of the granitoid gneiss and schists is marked by a band of peculiar gneiss which appears to be composed of the two members closely interlaminated, suggesting that the granite has been forced

in a molten condition between the laminæ of the schistose rock.

(*c*) While the main summits of the southern range are composed of a granite with little quartz, and much acicular hornblende (almost a syenite), the spur of Haimar and Jebel Aad consists mainly of a well marked *tourmaline-granite*, whose precise relation to the first-named has not been determined.

(*d*) The gneisses seem chiefly limited to the high ranges, the low country to the south being mainly formed of true granite rich in porphyritic felspars, while north of Wadi Nasb the areas occupied by the two types are sharply marked off from one another, differing in colour, and to a certain extent in surface features as well. Thus, the true granite country is usually more rugged, and has a distinct and characteristic pink shade.

(*e*) *Spherulitic Felsites* are very abundant in the district, and have been shown to form part of dykes penetrating the granite, &c., and not to be members of an outpouring of lava at the surface.

(*f*) No proof has been obtained of the existence *of basalt*, such as was stated to be present near Sherm by Burckhardt. The only black rock of any importance in that neighbourhood is the manganiferous gravel previously described.

In conclusion, it will be seen from these brief notes, that the igneous and metamorphic rocks themselves afford a wide field for speculation and study, and will be dealt with more fully when sections have been made of the specimens brought back for closer examination.